HEAVY MINERAL INVESTIGATION OF CARMEL BAY BEACH SANDS

by

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THESIS

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ABSTRACT

This investigation was conducted in order to identify the heavy minerals of the beach sands of Carmel Bay, and to analyze the distribution of these minerals. Carmel Bay offers the opportunity to study heavy mineral assemblages in a small isolated bay, internally divided by a submarine canyon, containing smaller pocket beaches influenced by several geological formations and two fresh water streams.

Correlation of the heavy mineral assemblage of each sample with the sample location clearly indicate that the beach sands can be divided into two principal mineral suites that are derivatives of the geological formations in immediate contact with the individual pocket beaches. The unique nature of each suite is preserved by natural obstructions that limit the influence of littoral drift and restrict the exchange of the beach sands.

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I. INTRODUCTION

A. OBJECTIVE AND PURPOSE

Several geological studies have been conducted in an effort to identify and describe the heavy minerals (specific gravity greater than 2.85) present in the beach sands of the California Coast. To date, however, no comprehensive study of the heavy minerals present in the beach sands of Carmel Bay (Figure 1) has been conducted. Carmel Bay was chosen as the study area because it presented the opportunity to investigate the heavy mineral assemblages in an area that is essentially isolated from outside influences. In addition, the shore of Carmel Bay is characterized by the variability of the surrounding geological structure, which should have a definite effect upon the distribution of the heavy minerals. The bay is bisected by the Carmel Submarine Canyon and further influenced by the outflow of two fresh water streams (Carmel River and San Jose Creek); these physical influences should also effect the heavy mineral assemblages of the beach sands. The Carmel River normally flows only in the winter during periods of maximum precipitation, and is dormant for the remainder of the year. San Jose Creek flows even less frequently. In order to understand the influence of the Carmel River and the San Jose Creek upon the heavy mineral distribution in the beach sands, samples were obtained during an interval when both of these streams were flowing.

B. BACKGROUND

Lawson (1893) described the geological formations and physiographic features of Carmel Bay. Lawson's effort, after three-quarters of a

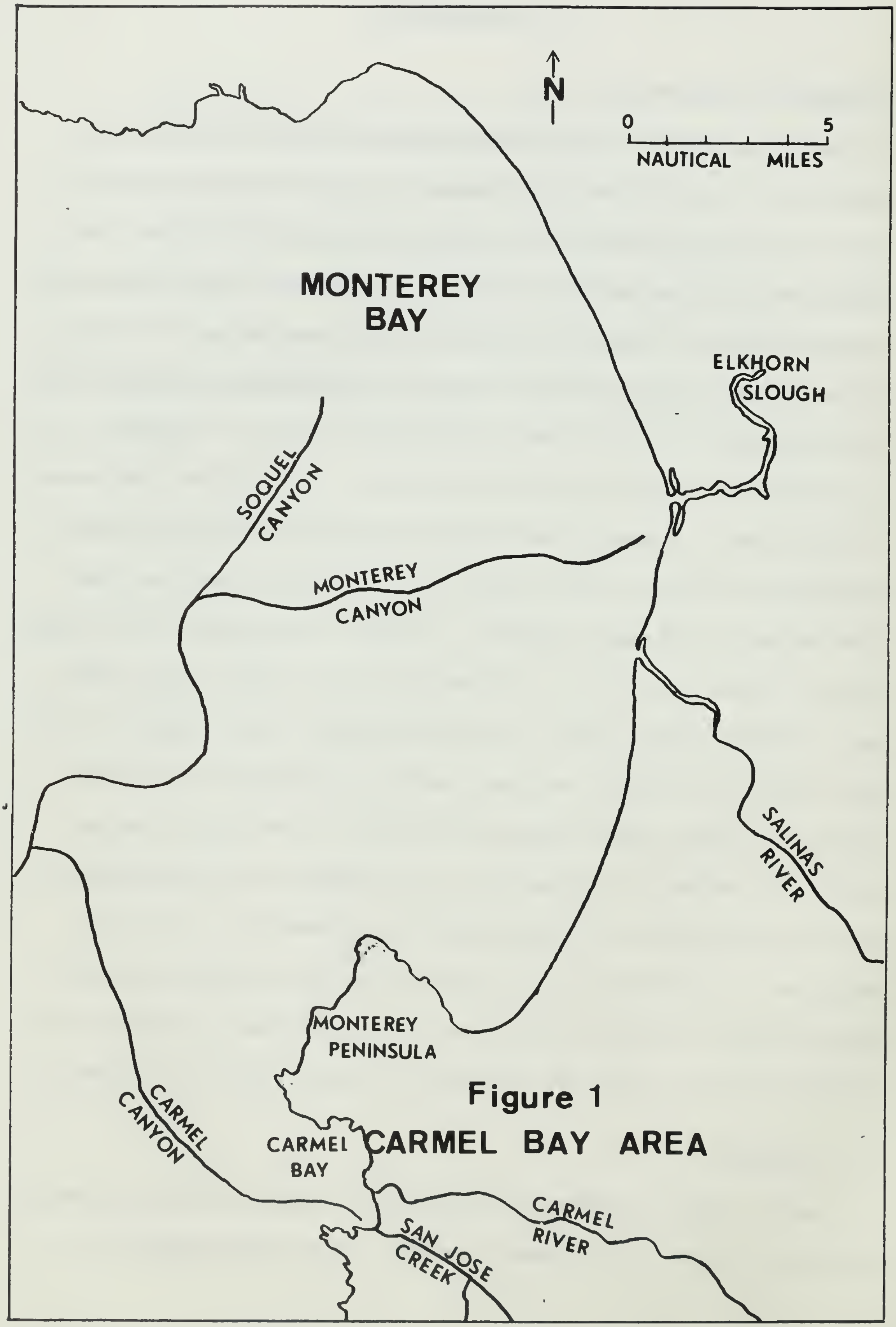

Figure 1
CARMEL BAY AREA

century, remains as the most complete geological description of this region of the California coast.

Bowen (1965) described the geological formations outcropping in Point Lobos State Park, which forms the southern boundary of Carmel Bay, and examined the interrelationships of these formations with the other geological formations of the general area.

Nili-Esfahani (1965) conducted a detailed investigation of the Paleocene strata present in the park. This investigation concerned itself with the structure, stratiography, lithology, paleontology and age determination of the Carmelo Formation.

Sayles (1966) made a study of the heavy minerals present in the beach sands of Monterey Bay, immediately to the north of Carmel Bay. He concentrated his attentions upon the influence of various sediment sources and littoral drift upon the heavy mineral distribution present in the bay. In general, he found that two distinct heavy mineral suites, hornblende-augite-hypersthene and hornblende-garnet, exist in Monterey Bay, and that the suites are separated from each other by the Monterey Submarine Canyon. Sayles concluded that these suites are primarily a reflection of the source area represented by the drainage area of the fresh water inputs into the bay. In spite of the proximity of Monterey Bay to Carmel Bay, the two bays are effectively separated by a large granitic promontory and influenced by different geological and oceanographic factors. Thus, the heavy mineral assemblages of Carmel Bay were not expected to closely resemble the assemblages identified by Sayles.

C. GENERAL DESCRIPTION

Carmel Bay is located approximately five miles south of the southern extreme of Monterey Bay, Monterey County, California. The bay is situated between two granitic headlands, Pescadero Point to the north and Point Lobos to the south (Figure 2). These headlands tend to isolate the bay from outside effects and render it an essentially closed sedimentary system. The bay is characterized by numerous small pocket beaches on its northern and southern periphery with three larger beaches on its eastern boundary separated from one another by granitic outcrops. The bay is further divided internally by the Carmel Submarine Canyon which originates immediately offshore from San Jose Creek. The San Jose Creek bed, which tends to follow the Blue Rock Fault (California Division of Mines and Geology, 1965), is a possible landward extension of the submarine canyon.

Carmel River empties into the bay north of the San Jose Creek mouth. The river meanders through an alluvial plain extending almost 20 miles inland with its drainage area being influenced by several geological formations (Sur Series, Santa Lucia, Paso Robles, and Monterey). In addition, evidence of recent terrace deposits can be seen extending several miles inland along the river bed.

The most important influence upon the physiography of the bay is the variability of the surrounding geological formations (Figure 3) which represent a geological record extending back for about a hundred million years (Table I).

The Santa Lucia Formation (Cretaceous) is a granodiorite porphyry which intruded into pre-existing sedimentary rocks. During intrusion and cooling of the granodiorite, the older marine sediments, the Sur

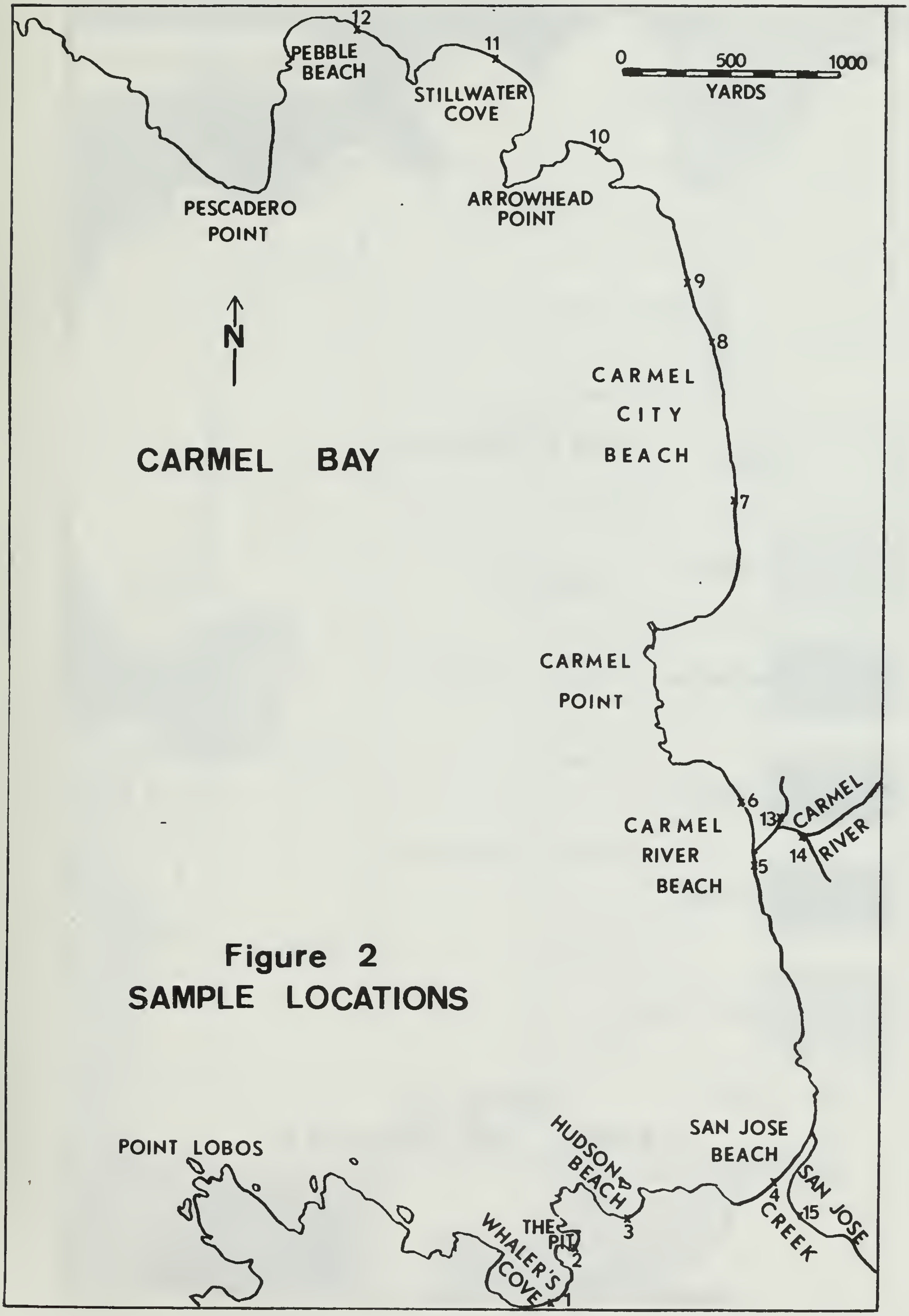

Figure 2
SAMPLE LOCATIONS

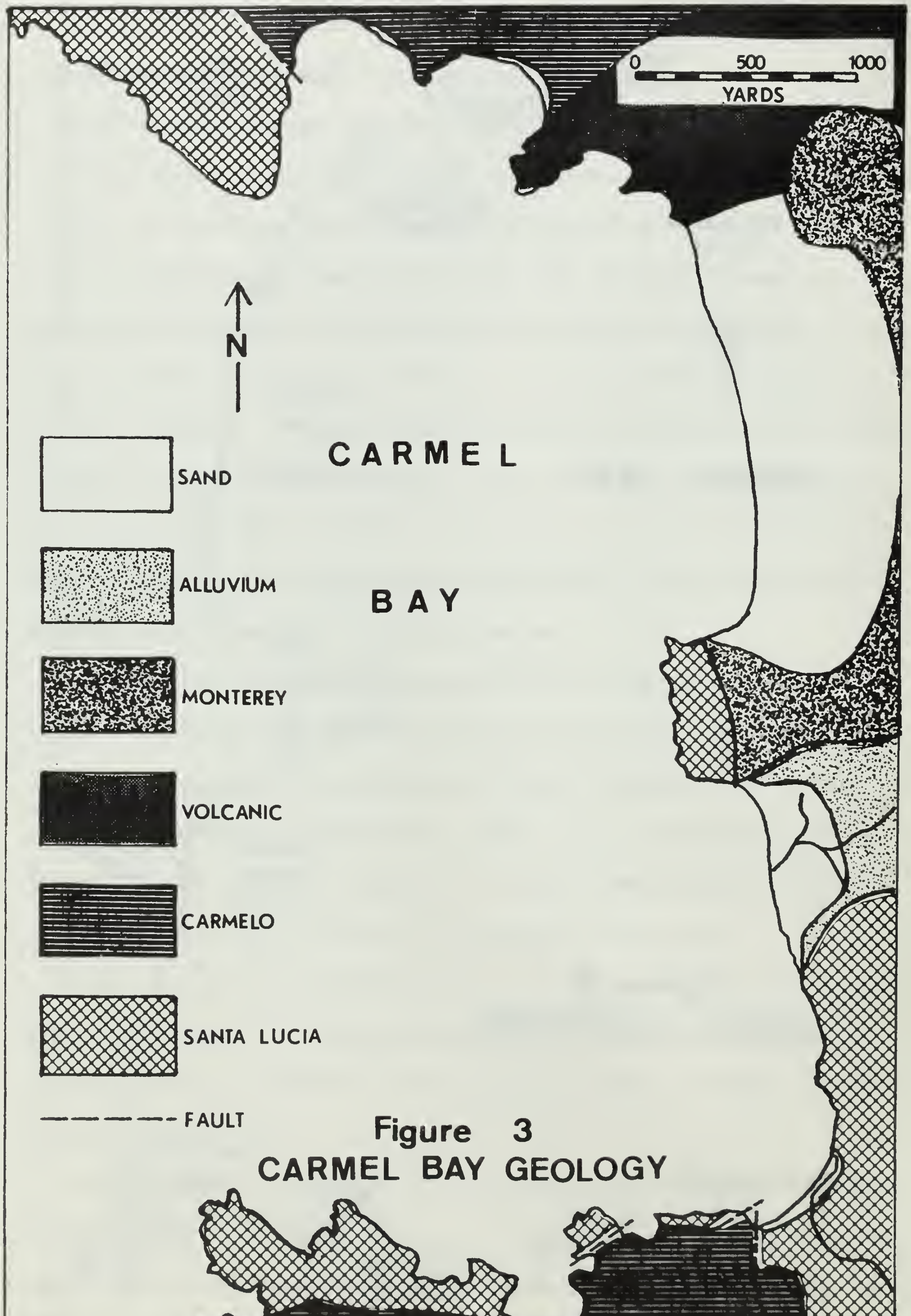

Figure 3
CARMEL BAY GEOLOGY

GEOLOGIC AGE			FORMATION
		Recent	Dune and beach sands
	Quaternary		Alluvial deposits
			Marine terrace deposits
		Pleitocene	Paso Robles
		Pliocene	
Cenozoic			Monterey
		Miocene	Volcanics
	Tertiary		Chamisal
		Paleocene	Carmelo
Mesozoic	Cretaceous		Santa Lucia
Paleozoic?			Sur Series

Table I

GEOLOGIC COLUMN OF CARMEL BAY REGION

Series (Pre-Cretaceous), were metamorphosed into dark grained schists and gneisses. Large masses of these metamorphic rocks outcrop in the Carmel River drainage region about 20 miles inland from the bay. The Santa Lucia Formation is traversed in all directions by aplite dikes varying in size from an inch to several feet in width. These dikes are much finer grained than the Santa Lucia proper, and are not appreciably porphyritic. In addition to these aplite dikes, there are narrow pegmatite dikes that also traverse the granodiorite. The pegmatite dikes are usually only a few inches in width and consist of a coarse granular aggregate (Lawson, 1893).

The Carmelo Formation (Paleocene) was deposited upon the eroded surface of the Santa Lucia. This formation is principally composed of a marine cobble conglomerate interfingered with thin-bedded sandstones, with minor strata of siltstone and clay shale. The pebbles in the conglomerate consist of red, purple and green porphyritic andesite, rhyolite, and metavolcanics (Table II) of unknown origin (Bowen, 1965). These pebbles are normally only a few inches in diameter and resemble stream detritus. The sandstones of the Carmelo Formation are predominately light-colored and composed principally of coarse-grained feldspar and quartz.

The next sedimentary formation in the sequence is the Chamisal Formation (Middle Miocene). This formation is a poorly consolidated cobble conglomerate and sandstone mixture containing white felsite cobbles and no colored volcanic rocks. The nature of the cobbles in the conglomerate makes the Chamisal Formation readily distinguishable from the Carmelo Formation (Bowen, 1965).

Andesitic tuff: Hard, black, dense, with aphanitic texture. The matrix constitutes 90% of the rock and is chloritic in composition. Phenocrysts of andesine with some quartz.

Meta-andesitic tuff: Dark green, hard, dense, with aphanitic texture. Matrix contains chloritic minerals and quartz (90%). Phenocrysts are of albite.

Meta-andesittic andesite: Greenish, hard, dense, with porphyritic texture. Phenocrysts consist of plagioclase and augite which have been strongly altered to epidote, calcite, chlorite, sphene, apatite and magnetite.

Porphyritic andesite: Light pink, hard, dense and porphyritic. Phenocrysts comprise as much as 30% of the rock. They consist of quartz, sodic plagioclase. They are angular and show some alterations. Chlorite and magnetite form the matrix.

Porphyritic rhyolite: Dark gray-brown, porphyritic, hard, and dense. Up to 20% phenocrysts which consist of orthoclase and quartz. Matrix is very fine mixture of chloritic minerals and fine quartz.

*Adapted from Nili-Esfahani (1965)

TABLE II

VOLCANIC PEBBLES FROM THE CARMELO FORMATION AT POINT LOBOS*

In a few places the Chamisal is overlain by a basalt. In other places, the Carmelo is in contact with the Monterey Formation, indicating that subaerial erosion took place prior to the deposition of the Monterey Formation (Middle Miocene).

The Monterey Formation is principally a thin-bedded siliceous marine shale. Due to the insolubility of the shale in water, the shale is peculiarly resistant to weathering and yields little sedentary soil (Lawson, 1893).

The only rocks in the area deposited during the Pliocene Epoch are represented by the Paso Robles Formation. This formation is the result of stream deposition of debris formed by the erosion of the Santa Lucia and Monterey Formations. The Paso Robles Formation is a poorly indurated mass of sands and gravels that form pale-colored cliffs and badlands.

Most of the flat land adjacent to the coast of the bay is the result of ancient coastal processes. Terraces, ancient beaches, deltas and sea cliffs of sand, clay, sandstone, incoherent beach pebbles and cemented conglomerates can be seen at elevations up to 800 feet above the present sea level surrounding Carmel Bay.

D. SEDIMENT TRANSPORT MECHANISMS

Heavy mineral assemblages may be influenced by sediment transport as well as geological features. Littoral drift, offshore drift, rip currents, and other transport mechanisms tend to redistribute beach sands throughout a particular bay.

Statistical wave data for the California coast has been compiled by National Marine Consultants (1960). These data indicate that 90% of all deep water wave energy in the area of Carmel Bay eminates from

the northwest quadrant. Wave refraction diagrams for Carmel Bay show that for waves incident from such a direction the induced littoral drift should be (1) eastward along the northern edge of Point Lobos, (2) southward near the Carmel River mouth, and (3) northward along the southern portion of Carmel City Beach. The granitic outcrops along the shore act to prohibit littoral drift for any appreciable distance; the drift is forced seaward by the outcrops and the sediment is carried away from the beach.

On frequent occasions a strong rip current was observed by the author at the center of San Jose Beach in the area of the Carmel Submarine Canyon head. The magnitude of the rip current was not measured, but disturbances and floating objects on the surface were observed to move at a speed on the order of tens of feet per minute.

While scuba diving in the Carmel Submarine Canyon region, Commander Donald Ferrin, USN (Ret.), (personal communication), has observed sandfalls on the northern rim of the canyon. These falls were observed in about 200 feet of water, 300 yards offshore, and flowed only intermittantly with activity restricted to periods of Carmel River outflow. In addition to sandfalls, sand chutes cut into the granitic rock north of the Carmel Submarine Canyon have also been observed (Wallen, 1968). The chutes were oriented parallel to the shoreline and varied in width up to a maximum of 10 feet. Most of the chutes were filled with coarse sand that was generally devoid of any sand-dwelling organisms.

II. PHYSIOGRAPHY

A. SOUTHERN POCKET BEACHES

Point Lobos is a rugged extension of the Santa Lucia granodiorite into the Pacific Ocean, forming the southwest boundary of Carmel Bay. The formation forms massive sea cliffs about 40 feet high with many rocks just offshore that extend well above sea level. The author has visually observed during a two year period commencing in the summer of 1967 that this area is normally subjected to the maximum wave energy present in the bay.

There are three small coves along the northern edge of Point Lobos that were investigated for the heavy mineral content of their beaches. The most substantial of these beaches is located at Whaler's Cove. The cove is bounded on the west by the Santa Lucia Formation and by the Carmelo Formation over the remainder of its perimeter. The Carmelo Formation occupies a small synclinal basin back of the cove and the attitude of the outcrops varies rapidly from horizontal at the center of the southern edge of the cove to steep dips over the remainder of its periphery. The Carmelo at Whaler's Cove is principally composed of a pebbly mudstone exhibiting graded bedding along the wave cut southern shore. The eroded material forms a medium grained sand with many pebbles throughout the beach deposits.

The second beach investigated was The Pit. The Pit is a very small cove that once contained chutes that were used to load ships with coal mined from the Santa Lucia Mountains to the east of the bay. This cove is characterized by steeply dipping strata of Carmelo conglomerate, sandstone and siltstone on the rim of the aforementioned syncline.

The third southern beach examined was Hudson Beach. This beach is separated from The Pit by a rocky sea cliff of granodiorite approximately 30 feet in height. Centered upon the southern shore of Hudson Beach is an outcrop of the Carmelo Formation that extends for about 100 yards. This portion of the Carmelo Formation consists of conglomerate, sandstone and mudstone strata in a steep fault contact with the granodiorite. The Santa Lucia Formation backs the eastern shore of Hudson Beach and extends eastward for several hundred yards, abruptly terminating at the southern edge of San Jose Beach which forms the eastern end of Carmel Bay. At this point there is an additional small outcrop of the Carmelo in contact with the granodiorite along a fault.

B. SAN JOSE BEACH

San Jose Beach is approximately 700 yards in length and lies at the front of the ancient stream delta formed by San Jose Creek. The beach is composed of a very coarse-grained quartz-feldspar sand with pebbles from the Carmelo Formation throughout in increasing concentration landward; additional smooth, flat pebbles of siliceous shale from the Monterey Formation are not uncommon. The beach face is very steep with the berm crest situated some 15 feet above the low water mark.

Landward of the beach in the surrounding hills there is evidence of ancient marine terraces extending up to elevations of several hundred feet, and also remnants of the previously mentioned delta.

San Jose Creek originates less than 10 miles inland and flows through a narrow and steep V-shaped canyon. The creek bed follows a path that takes it through the Monterey, Paso Robles and Santa Lucia

Formations in rapid succession. Normally, the flow of the creek is so meager that very little water ever reaches the shore. The creek enters the backshore near the center of the beach where it turns northward and runs parallel and in back of the berm crest, turning seaward again at the northern edge of the beach. During the rains experienced in the Winter of 1968-69, stream flow increased to such an extent that the creek broke straight through the berm crest on a line roughly joining the San Jose Canyon and the Carmel Submarine Canyon. The outflow lasted for a period of several weeks and during the maximum flood the author observed rocks up to a foot in diameter being carried out to sea. As the flow diminished, the creek bed eroded the berm crest progressively northward until the creek had attained its normal path.

At the northern end of this beach is a small outcrop of a poorly consolidated conglomerate containing angular pebbles and boulders of granodiorite and shale which may represent the remains of a small, relatively recent delta formed by San Jose Creek.

The northern boundary of San Jose Beach is formed by a low sea cliff of granodiorite that extends for more than a thousand yards northward to Carmel River Beach. Meager pocket beaches are interspersed along this sea cliff and are composed mainly of coarse sand deposits and large boulders derived from the Santa Lucia outcrop.

C. CARMEL RIVER BEACH

The Carmel River Beach extends northward from the Santa Lucia outcrop north of San Jose Beach for about 1200 yards, and is nearly 600 yards wide at the mouth of the Carmel River. The beach deposits sampled consisted of a coarse-grained quartz-feldspar sand with many small pebbles apparently derived from the Carmelo and Monterey

Formations. The southern portion of the beach has a gentle slope and is relatively narrow with its backshore being abruptly terminated by small sea cliffs cut into terrace deposits. At the river mouth the beach has its greatest width, extending inland more than one-quarter of a mile. The beach in this area is gently sloping with a pronounced storm berm several hundred yards inland of the shore line. During the summer and fall seasons the Carmel River is largely dormant, and, during this period of time, the berm crest closes off the river mouth forming a small fresh water lagoon on the backshore. As the beach extends northward, it narrows, and the slope of the beach face gradually increases to the point where the face is nearly vertical to the water at the northern edge of the beach.

In order to reduce the danger of severe flood damage, the mouth of the Carmel River was forced open by workmen of the Monterey County Flood Control and Water Conservation Board on January 18, 1969. During this period of time, the river remained near flood level for several weeks carrying large amounts of sedimentary debris to the ocean.

Carmel River Beach is separated from Carmel City Beach by a rugged outcrop of the Santa Lucia Formation. This granodiorite outcrop forms an expanse of small sea cliffs that contain no appreciable beach deposits.

D. CARMEL CITY BEACH

Carmel City Beach is the largest beach in the area of study. It extends northward from Granite Point for more than a mile and inland for almost 200 yards at its widest point. The beach consists of a fine white sand with very few pebbles. The beach is gently sloping throughout its entire extent, increasing in slope slightly towards the

north. The southern portion of the beach is flat and wide, terminating at a sandstone outcrop on the backshore. The northern portion of the beach narrows and is terminated inland by large sand dunes.

Carmel City Beach is bounded on the north by an outcrop of a vesicular basalt. The beach in this area consists of small amounts of coarse-grained quartz-feldspar sands interspersed with large pebbles derived from the basalt.

E. NORTHERN POCKET BEACHES

To the north of Carmel City Beach is a large outcrop of the Carmelo Formation that forms the landward boundary for two small pocket beaches. These pocket beaches are separated from the volcanic outcrop by a steep sea cliff of the Carmelo Formation. North of the sea cliff is Stillwater Cove and at the northern boundary of the bay is Pebble Beach. This secluded area has been observed by the author to be subjected to the least amount of wave energy occurring in the bay.

The beach deposits in Stillwater Cove are composed of a fine white sand with many paystreaks (localized concentrations of darker sands). These paystreaks are generally on the order of a foot in length and a few inches wide. Pebble Beach sand deposits are composed of medium-size sands with numerous pebbles derived from the surrounding Carmelo Formation.

The Carmelo Formation on the northern side of Arrowhead Point contains large cobbles and makes a nearly vertical contact with the basalt where there are masses of the conglomerate enclosed in the basalt immediately adjacent to the contact. The structure of the Carmelo Formation is not very apparent in this area. To the west of

Stillwater Cove, however, the structure is exposed with the strata dipping towards Pescadero Point at an angle of approximately 15° and can be followed without a break towards the Santa Lucia granodiorite at the point. The Carmelo Formation terminates sharply at a fault contact on the western edge of Pebble Beach. From this point, the Santa Lucia Formation continues practically uninterrupted along the shore to the town of Monterey.

III. PROCEDURES AND TECHNIQUES

A. SAMPLING

During the first week of April, 1969, fourteen surface samples were taken from the beach sands of Carmel Bay (Figure 2), and one additional sample was taken inland from both Carmel River (Sample 16) and San Jose Creek (Sample 15). Each sample contained approximately 500 grams of sand. The samples north of Granite Point were all taken from sand paystreaks of dark minerals, but no paystreaks were found south of this point. Whenever found, paystreaks were utilized in order to increase the concentration of heavy minerals present in each sample.

B. PREPARATION

Each sample was washed and split in order to obtain a working fraction of about 75 grams. The samples were then slowly oven dried and separated through a nest of sieves using 0.5 $\emptyset$ intervals from -1 $\emptyset$ to + 4 $\emptyset$ $[\emptyset = -\log_2(\text{grain diameter in mm/1mm})]$. The heavy minerals were then separated out of the fine sand size (3.0 $\emptyset$) using bromoform (specific gravity = 2.85). Several samples did not contain an adequate amount of heavy minerals in the fine sand size; in these cases, the heavy minerals were separated out of a coarser size fraction (2.5 $\emptyset$ for samples 10 and 12, 2.0 $\emptyset$ for sample 4). Generally, less than one gram of heavy minerals was obtained from each sample. Samples 4 and 10 yielded less than 100 grains of heavy minerals from each sample because the coarse sand present at the source areas of these two samples consists essentially of rock fragments as opposed to individual mineral grains.

Samples were split in order to obtain a representative amount and mounted in Lakeside 70 on a glass slide for analysis with a petrographic microscope. Approximately 300 heavy mineral grains of each sample fraction were identified and counted utilizing a micrometer click stage in order to obtain a representative statistical distribution of the minerals (Table III). Tertiary diagrams for various heavy minerals were constructed in order to visually display the characteristics of mineral suites (Figures 4-7).

C. MINERAL IDENTIFICATION

Mineral identification was accomplished by optical means using a petrographic microscope. Color and the existence of pleochroism, crystal habit, cleavage, fracture, relief, birefringence, extinction, and interference figure were all utilized as aids to identification. Kerr (1959) presents an excellent text on optical mineralogy that explains in detail this utilization of the petrographic microscope.

Table III

PERCENTAGE OF THE HEAVY MINERALS FOUND IN THE
HEAVY FRACTION OF THE BEACH SANDS OF CARMEL BAY

	Sample No.															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Opaques	38	41	72	6	6	23	4	62	75	46	75	34	4	7	4	6
Biotite	3	1		81	30	11	12	1	1			8	21	12	32	30
Hornblende	3	3	2	7	40	29	44	5	3	13	1	23	51	53	48	40
Garnet	13	29	11		5	23	15	20	13	26	13	19	8	9	2	6
Zircon	6	13	5		11	6	8	7	5	3	7	3	6	9	7	5
Augite	27	1	2	3	2	2	3	TR	TR	5		2	4	3	4	2
Rutile	2	2	1		1	TR	1				1	1		1		2
Apatite			1		2	1	2		TR		1	4	1		1	1
Aegerine-augite	1	1		1	1		1						1		TR	
Diopside		1			1								1	1		1
Enstatite													TR	TR		1
Hyperstene			1													

Note: TR (Trace) is less than 0.5% of heavy mineral fraction

Table III (Continued)

Sample No.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Epidote	4	4	1										TR	TR		1
Sphene	2	4	6	1	1	3	2	1	3	3	1	6	3	3	2	3
Olivine			1				6	TR								
Monazite																1
Kyanite	1				1	TR	2			3						1
Staurolite																1
Clinozoisite														1		1

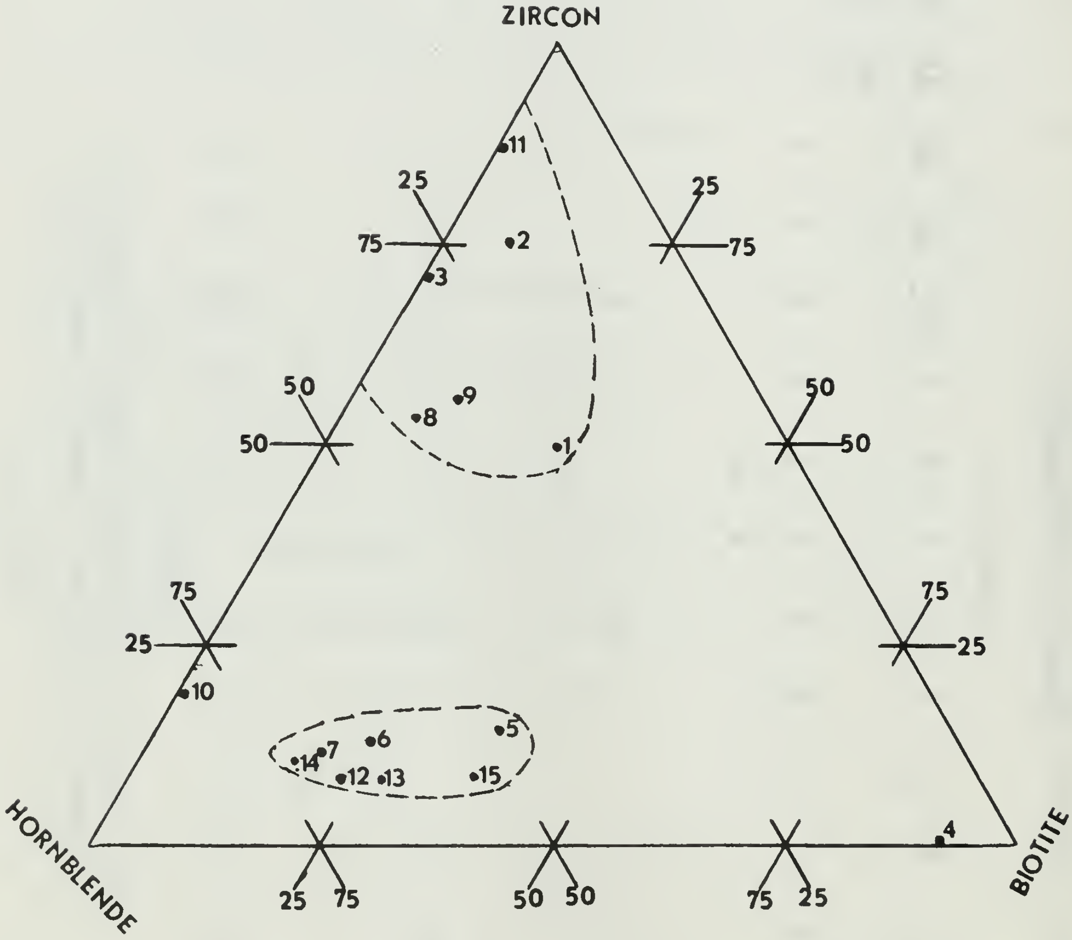

Figure 4

TERTIARY DIAGRAM: HORNBLENDE, ZIRCON, BIOTITE

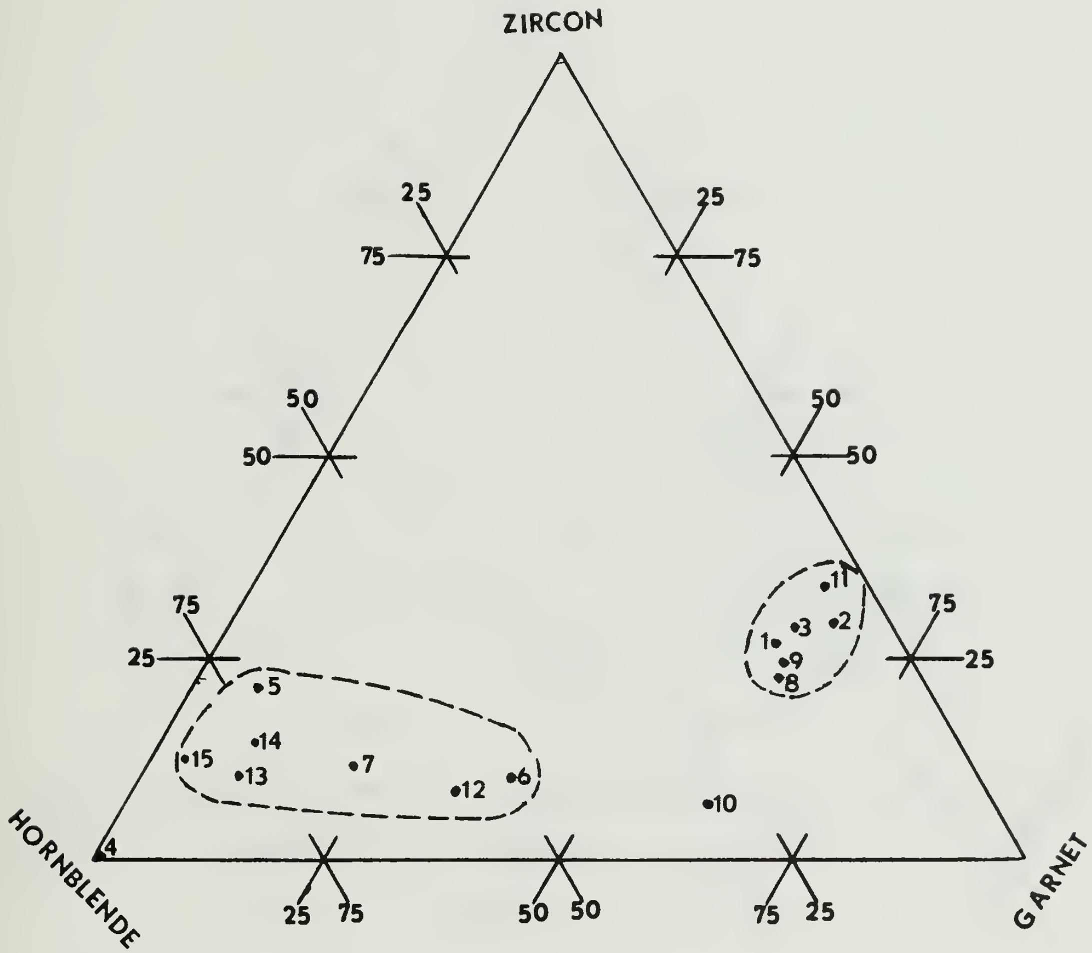

Figure 5

TERTIARY DIAGRAM: HORNBLENDE, ZIRCON, GARNET

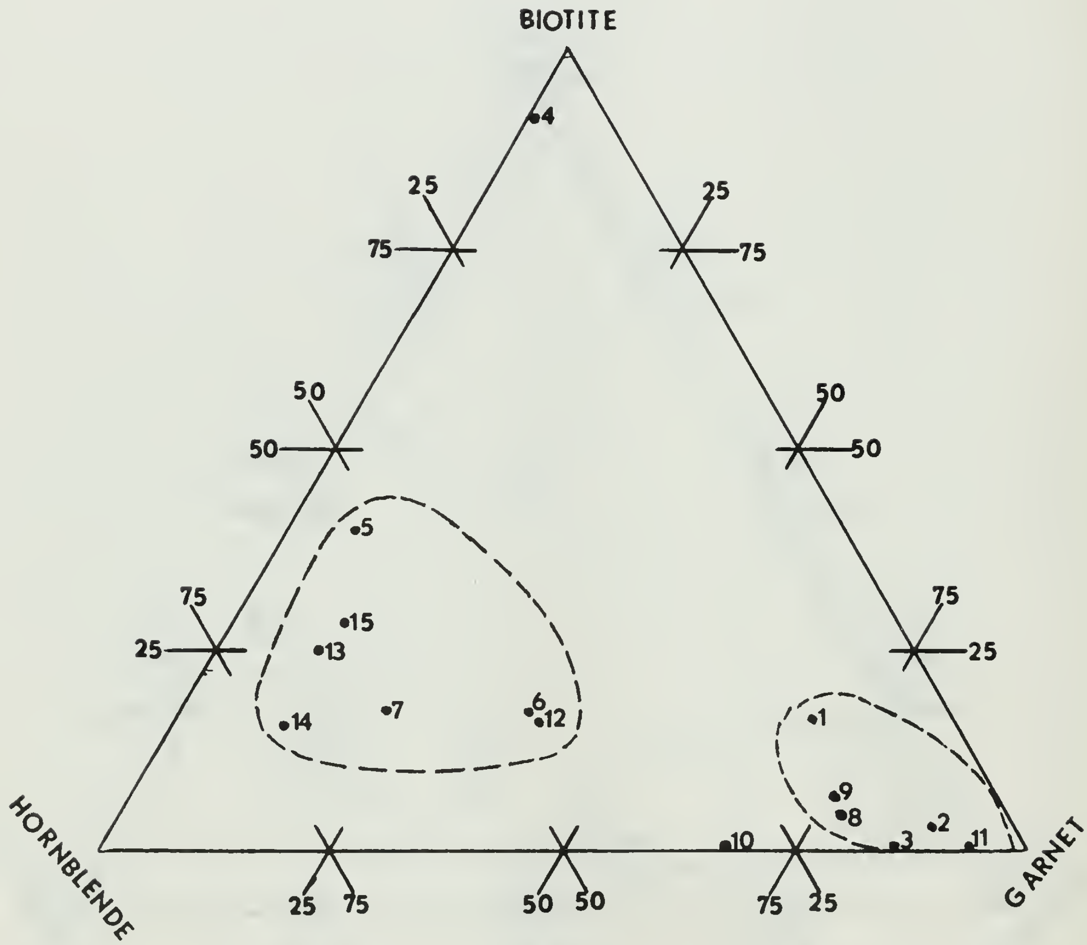

Figure 6

TERTIARY DIAGRAM: HORNBLENDE, BIOTITE, GARNET

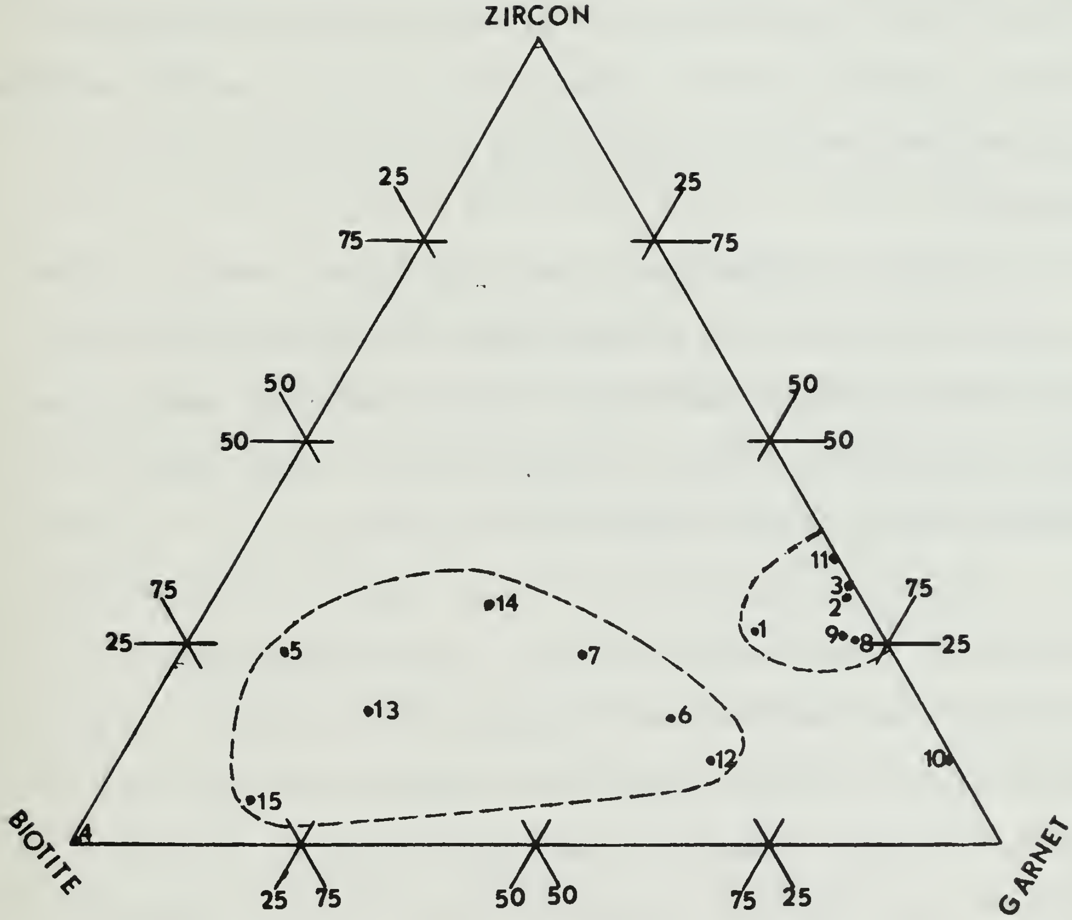

Figure 7

TERTIARY DIAGRAM: BIOTITE, ZIRCON, GARNET

IV. RESULTS OF HEAVY MINERAL STUDY

A. MINERAL DESCRIPTION

1. Major Constituents

Opaque minerals were found throughout the sand samples and constituted the largest percentage of heavy minerals identified. In reflected light, the opaque grains appeared black with a metallic luster. Magnetic separation (using a small permanent magnet) and grain appearance indicated that nearly all of the opaque constituents were magnetite.

Plates of biotite were found throughout the samples with the principal concentration at San Jose Creek. The plates were reddish-brown and yellow-brown showing only slight pleochroism; commonly the grains were made up of platelike aggregates with ragged edges. Inclusions and pleochroic haloes were very common.

Green and brown varieties of hornblende with marked pleochroism were found throughout the bay. The green variety tended to be prismatic with well defined striations on the surface. The brown variety tended to be more rounded with inclusions and pleochroic haloes. There was a clearly defined preponderance of the green variety in the vicinity of the Carmel River and San Jose Creek and of the brown variety in the vicinity of the Santa Lucia Formation.

Garnet was a well distributed constituent throughout the samples. The grains were angular to rounded with semi-conchoidal fracture surfaces. The grains were principally colorless or salmon pink with a few grains that were red or orange in color. Some of the

grains showed strong pitting and etching, especially in the southern coves. Inclusions were common, especially in the colorless variety.

Zircon was found in moderate quantities in all of the samples. The grains were predominately colorless but a few pale pink (hyacinth) grains were observed. Lath-like inclusions were very common in many grains. The zircon observed in most of the samples showed a tendency to be more rounded than the euhedral grains found at the mouth of the Carmel River.

Small quantities of augite were found in most samples, but it was the primary transparent heavy mineral found at Whaler's Cove. The grains were pale greenish with faint pleochroism. The great majority of the grains were well worn and irregular. More than 13% of the augite grains found at Whaler's Cove showed an anamolous wavy extinction that was not observed elsewhere. These grains were slighly darker, of a deeper green color, and less weathered than the other grains found in the area.

2. Minor Constituents

In addition to zircon, rutile and apatite were the only other uniaxial heavy mineral found in the samples. Colorless euhedral grains of apatite were found in small amounts distributed throughout most of the samples. Rutile did not exceed two per cent in any of the samples studied. The rutile grains were commonly found as broken prismatic crystals with a few grains exhibiting twinning.

Collectively, the pyroxene group was represented in most samples. With the exception of augite, however, specific members of the group were found only intermittently in the samples. Aegerine-augite grains were slightly pleochroic green in color and euhedral

stubby prisms in form. Colorless irregular grains of diopside were present and exhibited typical pyroxene cleavage. Colorless enstatite grains were also found associated with the Carmel River. A trace of colorless hypersthene (less than 0.5% of the total heavy mineral fraction) was found only on Hudson Beach.

Two members of the epidote group, clinozoisite and epidote, were found in a few samples. The clinozoisite grains were colorless and elongated. Epidote was characteristically elongated and pale green in color with faint pleochroism. The epidote grains in the southern portion of the bay showed a more jagged appearance than the specimens found elsewhere.

Sphene was found to be a minor constituent in all samples. Most grains were yellow-brown in color with a few showing pleochroism from yellow-brown to greenish-yellow. The pleochroic grains tended to be more rounded than the non-pleochroic grains, which were angular or often euhedral. A few grains did not show complete extinction but retained an anomalous bluish color.

A small number of colorless anhedral grains of olivine were found in several samples.

Small amounts of monazite, kyanite and staurolite were found associated with the Carmel River. Monazite was found as colorless egg-shaped grains. Gray kyanite grains with broad elongated sections, jagged terminations, and surface striations were also present. Porous, "swiss cheese" appearing grains of staurolite were found in trace amounts. These grains were pleochroic from light-yellow to orange-yellow.

B. SUITE CHARACTERISTICS

Tertiary diagrams constructed for all possible combinations of hornblende, biotite, zircon, and garnet indicate that two principal heavy mineral suites exist in the beach sands of Carmel Bay; these will be designated as the Carmelo Suite and the Santa Lucia Suite. Beaches in close proximity to the Carmelo Formation are characterized by large relative amounts of zircon and garnet, and are members of the Carmelo Suite; beaches in close proximity to the Santa Lucia Formation are characterized by an abundance of hornblende with significant amounts of biotite, and are members of the Santa Lucia Suite.

1. Southern Pocket Beaches

These beaches, characterized by large quantities of zircon and garnet and smaller quantities of biotite and hornblende, are members of the Carmelo Suite. Garnet, sphene and zircon are found throughout the southern beaches in quantities comparable to those found elsewhere in the bay. Tertiary diagrams show very good correlation for these three beaches. Rutile was found in all samples except those from the Carmel City Beach, but the greatest percentage occured at Whaler's Cove and The Pit (two per cent). Augite was a very significant constituent of the sample from Whaler's Cove (27%). It is noteworthy that this sample was the only one taken from a beach derived almost exclusively of debris from the Carmelo conglomerate. Epidote was present throughout the southern pocket beaches (maximum of four per cent) and noticeably absent elsewhere in the bay.

2. San Jose Beach

San Jose Beach sampling consisted of a single sample which contained the smallest assortment of heavy minerals and the largest occurrence of any single heavy mineral (81% biotite). Moderate amounts of opaque minerals and hornblende were present as well as lesser amounts of sphene and pyroxenes. This sample did not correlate with either of the two major suites identified.

The San Jose Creek sample varied significantly from the sample taken at the San Jose Beach. The creek sample contained 51% hornblende and only 21% biotite, and is included as a member of the Santa Lucia Suite. In addition to the heavy minerals occurring on San Jose Beach, the creek sample contained moderate amounts of zircon and garnet with lesser amounts of apatite, enstatite and diopside.

3. Carmel River Beach

The Carmel River Beach was represented by two samples taken from the beach sands near the mouth of the Carmel River. The beach is characterized by the greatest amount of hornblende found in any of the samples (40% maximum) and is a member of the Santa Lucia Suite. Greater concentrations of zircon, hornblende and biotite were found in the sample south of the river mouth than were found in the sample to the north. The opposite distribution occurred for opaque minerals and garnet. Smaller amounts of rutile, apatite, kyanite, sphene and members of the pyroxene group were found in both samples.

The samples taken from the Carmel River bed and the fresh water lagoon inland of the river mouth were very similar to the samples taken near the river mouth. Small amounts of monazite, staurolite, epidote, enstatite and hypersthene were found in the sample taken from the Carmel River bed, but were not found in the beach samples.

The sample taken about one-half of a mile north of Carmel Point exhibits a highly significant mineral distribution. Even though this sample is separated from the Carmel River Beach by Carmel Point, tertiary diagrams indicate that the mineral distribution more closely resembles that of the Carmel River Beach and the Santa Lucia Suite than the Carmel City Beach samples.

4. Carmel City Beach

The Carmel City Beach was represented by two samples from the northern portion of the beach and the sample adjacent to the southern edge of Arrowhead Point as well as the previously mentioned sample north of Carmel Point. Opaque minerals and garnet collectively dominate these samples, comprising more than 70% of any particular sample. In turn, the opaque mineral fraction exceeds that of garnet by an average of three to one. Tertiary diagrams show very good correlation for the two samples taken from the Carmel City Beach, but only moderate correlation for the sample south of Arrowhead Point. Biotite was noticeably absent or occurred in very small amounts in these samples. Moderate amounts of zircon and hornblende, with lesser amounts of apatite, olivine, sphene and augite were also present. The beach sands of the northern portion of Carmel City Beach, with the exception of the Arrowhead Point sample, are included as members of the Carmelo Suite.

5. Northern Pocket Beaches

The northern pocket beaches are represented by the samples taken from Stillwater Cove and Pebble Beach. The Stillwater Cove sample displayed a marked similarity to the southern pocket beaches in that it is almost identical to that of Hudson Beach and very similar

to the distribution of The Pit. This sample is a member of the Carmelo Suite. The heavy mineral distribution at Pebble Beach is very similar to the two samples immediately to the north and south of Carmel Point, with greatest resemblence to the southern sample. Therefore, this sample is included as a member of the Santa Lucia Suite.

V. CONCLUSIONS

The heavy mineral distribution of the various samples obtained from the shores of Carmel Bay can be classified into two major heavy mineral suites whose characteristics are primarily determined by the geological formation in the immediate vicinity of each sample. The samples containing relatively large amounts of zircon and garnet are members of the Carmelo Suite and are generally under the influence of the Carmelo Formation; the samples containing relatively large amounts of hornblende and biotite are members of the Santa Lucia Suite and are under the influence of the Santa Lucia Formation. The southern pocket beaches, Carmel City Beach and Stillwater Cove are members of the Carmelo Suite, whereas the Carmel River Beach and Pebble Beach are members of the Santa Lucia Suite. The unique nature of each suite is maintained by the lack of a transport mechanism between the various beaches.

A. SOUTHERN POCKET BEACHES

The three beaches located on the northern side of Point Lobos are essentially isolated from the remainder of the bay. The physical nature of Point Lobos is such that littoral transport of heavy minerals from a remote source is negligible, and the deep waters associated with Carmel Submarine Canyon prohibit the input of sand derived from a northern source. Therefore, the heavy minerals found on these beaches must be a product of the Santa Lucia and Carmelo Formations. Hornblende and biotite are principally derived from the granodiorite; opaque minerals, garnet, rutile and epidote are principally a result of the

Carmelo. The anomalous preponderance of augite present at Whaler's Cove indicates that the conglomerate stratum found in the cove is also a source of this mineral.

B. SAN JOSE BEACH

The coarseness of the sands at San Jose Beach obscures the heavy minerals contained in these deposits. Under normal circumstances San Jose Creek is dry and cannot be considered as a source of beach material. Furthermore, sand is carried into the Carmel Submarine Canyon by rip currents and the normal seasonal process of sand migration and is lost to the beach. Therefore, sand must be derived from the granitic outcrops to the north and south of San Jose Beach.

The preponderance of biotite present at San Jose Beach may be the result of either a nonrepresentative sample or the result of the hydrodynamics of its crystal form. Due to its flaky structure, a greater threshold velocity is required to place biotite grains in suspension than would be required for more symetrical grains of equal mass. Therefore, once the biotite has been deposited on the beach, it will have a tendency to remain on the beach while other mineral grains of the same size may be moved away.

The apparent stability of the sand budget at San Jose Beach indicates that the San Jose Creek sediment is not required by the beach in order to maintain a balance of sand. The marked difference between the heavy mineral fraction obtained from the San Jose Creek sample and that of San Jose Beach create strong doubts that the creek is a principal source of beach material even when it is flowing. The

inertial flow created at the mouth of the creek probably carries practically all of the San Jose Creek sediment directly into the Carmel Submarine Canyon.

C. CARMEL RIVER BEACH

The sands of the Carmel River Beach are primarily derived from the Santa Lucia outcrop at Carmel Point. High energy waves incident upon the point erode the granodiorite, and the sand debris is carried away, both northward and southward, by littoral drift. The northward transport is primarily responsible for the heavy mineral distribution found on the southern portion of Carmel City Beach; the southern transport is partially responsible for the distribution to the south. During periods of time when the Carmel River mouth is closed to the sea, the southern transport probably distributes the sands from Carmel Point over the entire shoreline of the Carmel River Beach. The southern extreme of this beach is terminated by another granitic outcrop that serves to force the southerly transport seaward. It is likely that the sand found in the offshore sand chutes by Wallen was partially derived from Carmel Point and transported southward until forced seaward by the deflected littoral drift. During periods of time when the Carmel River mouth is open to the sea, the Carmel River bed-load is a contributor to the beach sands at the river mouth; however, sandfalls observed in Carmel Submarine Canyon indicate that most of the Carmel River sediment is carried directly into the deep water of the canyon and lost to the beach.

D. CARMEL CITY BEACH

The origin of the sands of Carmel City Beach remains unknown. Tertiary diagrams show a marked similarity between this beach and

samples located in areas under the influence of the Carmelo Formation. However, the Carmel City Beach is effectively isolated from the Carmelo Formation by Arrowhead and Carmel Points. The origin and composition of the sand dunes at the back of the Carmel City Beach is also unknown, but it is conceivable that these dunes may be a source of the sands of Carmel City Beach.

E. NORTHERN POCKET BEACHES

The two northern pocket beaches are located in a very low wave energy area and do not exchange sediments with the remainder of the bay to any great extent. Stillwater Cove beach sands represent material locally derived from the surrounding Carmelo Formation. On the other hand, the beach sands of Pebble Beach exhibit the influence of the Santa Lucia Formation. These sands are eroded from Pescadero Point region and distributed throughout Pebble Beach by littoral drift. The projection between Pebble Beach and Stillwater Cove apparently prohibits the transport of sands from the Pescadero Point region into Stillwater Cove.

VI. FUTURE WORK

This study has exposed many problems that must be solved in order to fully understand the geology and dynamics of Carmel Bay. A careful petrographic study of the surrounding geological formations is required in order that the results of this investigation can be fully interpreted. The strata of the Carmelo Formation must be studied in detail in order to identify the mineralogical variation of its several members. The composition of the sand dunes located at the northern end of Carmel City Beach should also be investigated. The influence of San Jose Creek and the Carmel River will not be completely understood until their mass transports are known, and the transport of sand into the Carmel Submarine Canyon is measured. Measurements of littoral drift may be of utmost importance. An analysis of the subtle but significant differences among the various minor heavy mineral constituents and the light mineral distribution throughout the beach sands of the bay would provide additional insight into the geological processes at work in this area.

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13. ABSTRACT

This investigation was conducted in order to identify the heavy minerals of the beach sands of Carmel Bay, and to analyze the distribution of these minerals. Carmel Bay offers the opportunity to study heavy mineral assemblages in a small isolated bay, internally divided by a submarine canyon, containing smaller pocket beaches influenced by several geological formations, and two fresh water streams.

Correlation of the heavy mineral assemblage of each sample with the sample location clearly indicate that the beach sands can be divided into two principal mineral suites that are derivatives of the geological formations in immediate contact with the individual pocket beaches. The unique nature of each suite is preserved by natural obstructions that limit the influence of littoral drift and restrict the exchange of the beach sands.

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